Building Classification and Seismic Vulnerability of Current Housing Construction in Malawi

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Abstract

Malawi experiences multiple natural hazards with severe effects on the population and the economy, amid challenging conditions of a rapidly degrading environment and limited resources. Recently, the Government of Malawi has taken the first major step to implement the national disaster risk management policy in close partnership with international aid organisations. Local communities and housing conditions are key components for achieving sustainable development and for reducing the impact of natural disasters. This study presents the results of a recent building survey conducted in Central and Southern Malawi to understand the current situation of housing construction in Malawi more accurately. The survey focussed on the informal housing construction sector with respect to seismic vulnerability. The observed characteristics of local buildings are compared with the global building classifications that are widely used for evaluating seismic vulnerability of structures. Building typologies that are defined based on international building databases and those observed in the field are different, highlighting the importance of obtaining more realistic building information for seismic risk assessment.

Keywords: *Building survey, building classification, seismic vulnerability.*

1. Introduction

Malawi is facing various economic and social problems, including rapid population growth, a low-income volatile economy, and a fast-degrading environment. Concurrently, urbanisation is occurring at an increasing rate of 3.8%, changing the risk profile of the country rapidly (UN-Habitat, 2010). The country is prone to multiple natural hazards, including floods, drought, strong winds and hailstorms, landslides and earthquakes. More than 21.7 million people were cumulatively affected by natural disasters between 1979 and 2010, claiming more than 2,500 fatalities. For instance, economic loss due to the 2015 flood event in the Lower Shire Basin alone was estimated to be MWK145,000 million or US$335 million, i.e.

approximately 5.0 percent of Gross Domestic Product (Government of Malawi, 2015a,b). Since Malawi is located within the East African Rift System (Hodge et al., 2015), seismic hazard is not negligible. In the past, large earthquakes of moment magnitude 7+ occurred in the rift (e.g. 1910 Rukwa, Tanzania and 2006 Mozambique earthquakes), while the two most recent events in Malawi,1989 Salima and 2009 Karonga, caused major damage, resulting in economic loss of about US$28 million and US$13.6 million, respectively (Chapola and Gondwe, 2016).

The built environment in Malawi, particularly housing construction, has a crucial influence in determining the socioeconomic impact of natural disasters and in achieving environmentally sustainable, affordable solutions (Ngoma, 2005). Yet, houses in local communities are one of the most vulnerable elements for a variety of reasons: (i) poor quality of construction materials, (ii) poor and variable construction practice, and (iii) lack of building design and construction provisions for natural disasters. Moreover, facing other pressing needs, it is not easy for Malawian households to invest in safety and preparedness against possible natural hazards, the return on which only may be realised in the future.

Responding to the recent crises triggered by natural hazard events, the Government of Malawi published the national disaster risk management policy, aiming at more coordinated actions by various governmental departments and non-governmental organisations to achieve disaster risk reduction and sustainable development effectively (Government of Malawi, 2015b). The Department of Disaster Management Affairs, in close partnership with other governmental agencies (e.g. Ministry of Lands and Housing and Departments of Housing and Buildings) and various international aid organisations (e.g. DFID, GFDRR, Red Cross, UN-Habitat, UNDP, and World Bank), play a key role in implementing disaster risk management programmes in Malawi. As part of these joint efforts, the recent publication of ‘Safer Housing Construction Guidelines’ (Bureau TNM, 2016) aims to serve as standard reference for housing construction in the upcoming years and contribute towards developing more resilient local communities/population against natural disasters. The guidelines contain procedures, with graphical explanations, for site selection and house construction which are adaptive to multiple environmental hazards in Malawi, using local workforce and materials (e.g. burnt bricks), ensuring that the methods are accessible to local artisans. Several options for selecting adequate construction materials and details are available in the guidelines to meet different budgetary constraints of the owners.

Although the guidelines are based on current best practice, they are mainly qualitative and prescriptive, lacking quantitative evaluations of the improvements. Currently, a gap exists between actual and targeted/aspired characteristics of the building stock in Malawi. As a result of these challenging situations, a large population may end up with some transitional phase in terms of housing, remaining in vulnerable conditions (UN-Habitat, 2010). To promote the transformation into more resilient permanent housing, the building characteristics of the current housing stock in Malawi need to be understood and the risk needs to be quantified more accurately.

As the first step towards this goal, this study investigates the characteristics of the current building stock by conducting a building survey in Central and Southern Malawi (July 2017). Subsequently, a building classification scheme for current houses in Malawi is proposed from a structural (earthquake) engineering viewpoint. The developed building classification method is related and compared to existing international building classification schemes for seismic vulnerability assessments. Implications of using more realistic building stock information, instead of global data, are discussed.

2. Building Survey in Central and Southern Malawi

A building survey was conducted by the authors in July 2017, in areas susceptible to seismic hazard in Central and Southern Malawi, based on the tectonics around the southern part of Lake Malawi (Hodge et al., 2015; Chapola and Gondwe, 2016; Goda et al., 2016).In the following, building survey results are summarised by taking the Malawi National Census (National Statistical Office of Malawi, 2008) as a reference. In the 2008 Census, houses were classified as: (a) 'traditional', made of rammed earth, Daub and Wattle or timber walls and lightweight thatched roofs, (b) 'semi-permanent', made of unburnt clay bricks and thatched roofs, and (c) 'permanent', made of burnt clay brick and iron sheet roofs. The nationwide proportions of traditional, semi-permanent, and permanent dwelling types were 28%, 44%, and 28%, respectively.

2.1 Methodology

Prior to the survey, demographic features of the target areas, such as population and household numbers, were gathered from the 2008 Census and inspection of Google Earth satellite images. Eight enumeration areas (EA) were selected as representative of different towns and villages urban and semi-rural built environments. These areas cover secondary-urban district centres and small townships/market towns in five different locations (Figure 1): Salima, Mtakataka, Golomoti,Balaka, and Mangochi. From a seismic hazard perspective, Salima suffered significant damage from the 1989 earthquake (Chapola and Gondwe, 2016), whereas Mtakataka, Golomoti, and Balaka are close to the Bilila-Mtakatakafault where the potential seismic risk be high, and Mangochi is located near the Malombe and Mwanjage faults (Hodge et al., 2015). Because the areas covered by this survey were limited due to available resources, the results are not intended for generating a complete and comprehensive building stock database for the region. Rather, they should be used as supplementary information to modify the existing more extensive data (e.g. national census) in light of current rapid demographic changes in Malawi (UN-Habitat, 2010).

In each EA, two types of building surveys, i.e. quick walk-through surveys and detailed surveys of individual buildings were performed. During the surveys, GPS tracking was used to record the locations of the inspected buildings and areas. Typical examples of the walk-through and the detailed surveys of individual buildings are presented in Figure 2, for Salima, EA 20520712. The walk-through survey was aimed at counting and classifying all buildings in the EA in a way similar to the 2008 Census procedure, based on wall material types: i.e. mud (traditional), unburnt brick (UB/semi-permanent), and fired brick (FB/permanent). In addition, other structural characteristics that affect seismic vulnerability were considered, such as wall thickness (single-skin or double-skin walls), the presence of lintels above openings and their types (wooden, concrete, or concrete ring beam), connections between walls (strong or weak) the building shape on plan (regular or irregular), and the roof shape (mono-pitched, gable or hipped). Regarding foundations, which were visually inspected on site, in traditional buildings these are completely absent, while in permanent and semi-permanent buildings, they are built as follows: plinth filled with compacted soil, plinth walls with concrete strip footing, plinth beams or slab (Novelli et al., 2018).

From a structural engineering perspective, more details, such as building external and internal dimensions, sizes of piers and openings, mortar material type, type of brick bonding, thickness of joints, and support conditions, are needed. To collect this information, a few representative buildings within each EA were selected for detailed inspections and measurements. The geometry and layout of 16 typical buildings (both outside and inside) were measured in detail using a laser instrument, tape, and Google Tango devices (i.e. quick photographic survey). In addition, a quicker semi-detailed survey was implemented in Mtakataka and Balaka to estimate the external building dimensions of 1 in every 5 buildings and to record key structural characteristics (brick and mortar material, roof type, shape regularity, regularity of openings and piers, support conditions, etc.). An overall quality rating of the building condition with respect to obvious structural deficiencies and maintenance issues was also assigned to these houses. In total 52 buildings were surveyed in this way.

2.2 Survey results

The results of the quick walk-through survey are summarised in Table 1. The numbers of buildings in most EAs agree well with the number of households in the 2008 Census records. The differences between the census data and our survey results may be due to several reasons: (i) non-residential buildings were included in the building count, (ii) actual boundaries of the EAs may differ from those indicated in the 2008 Census, and (iii) surveyors' errors, such as double-counting, might have occurred. It is also reasonable to assume that some of these areas have expanded since 2008 due to urbanisation. Despite the possible errors in our survey results, overall, it appears that recorded percentages of the different building typologies are reliable for drawing useful observations regarding the current categories of the housing stock in the surveyed areas.

The surveyed locations, according to the observed similarities of building typologies, can be grouped into: Group 1 - 'secondary-urban areas with presence of the formal construction sector' (Salima 712); Group 2 - 'secondary-urban areas developed by the informal construction sector' (Salima 717 & 718, Mangochi 704, and Balaka); and Group 3 - 'sub-urban areas and rural townships/market town areas' (Mangochi 708, Golomoti, and Mtakataka).

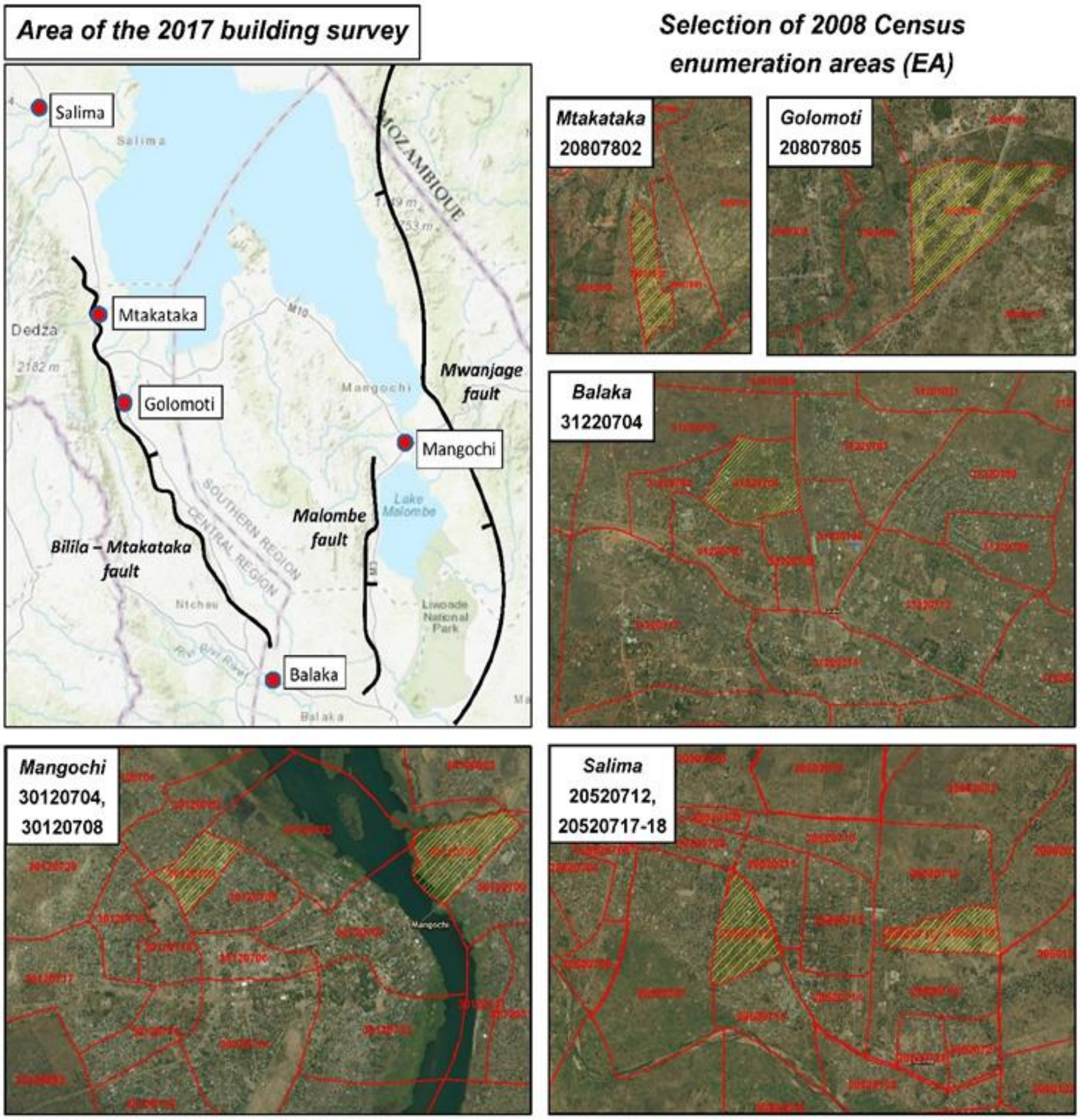
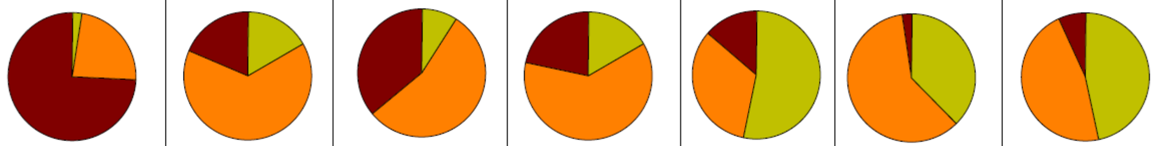
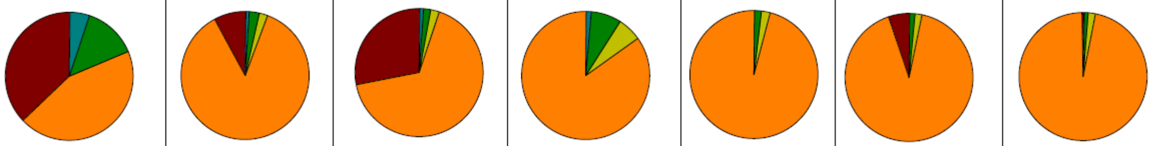
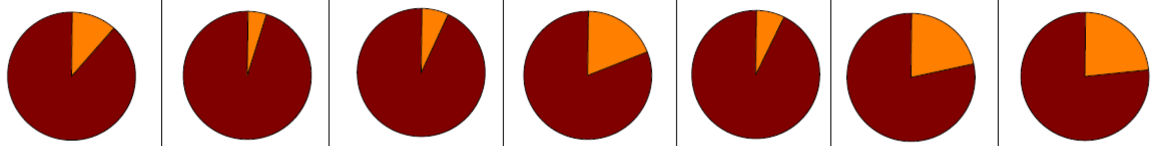
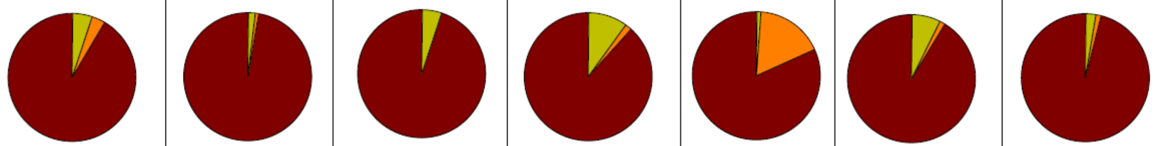


Figure 1: Areas of the 2017 building survey and selected 2008 Census enumeration areas (EA).

Figure 2: Quick walk-through and detailed building inspections in Salima EA20520712.

Table 1: Summary of quick building survey results per enumeration area.

City/Township	Salima		Balaka	Mangochi		Golomoti	Mtakataka
EA	20520712	20520717 - 18	31220704	30120704	30120708	20807805	20807802
Area description	Urban, with formal housing	Urban, informal housing	Urban, informal housing	Urban, informal housing	Sub-urban market town	Rural market town	Rural market town
2008 Census	**261**	**294**	**461**	**466**	**351**	**466**	**326**
2017 building survey	**266**	**238**	**330**	**409**	**410**	**925**	**449**
Masonry type FB, double skin FB, single skin UB & Traditional							
Lintel type Uknown None Timber Concrete Ring Beam							
Building shape Regular Irregular							
Roof shape Gable Hipped Mono-pitched							

Compared with the 2008 Census data, the summarised results for the three groups presented in Figure 3 indicate that the proportions of permanent buildings (i.e. fired brick masonry) are significantly greater than those indicated in the Census data. The characteristics of the housing stock, especially in urban areas have moved towards the permanent housing type. The percentages of the traditional housing type in all areas were negligible; normally less than 1%. In Table 1 they are included along with unburnt brick (semi-permanent) buildings. Semi-permanent buildings were known to be less common than the national average in secondary-urban areas in Central and Southern Malawi (Ngoma, 2005; UN-Habitat, 2010). They remain prevalent in rural areas, but their percentages are decreasing continuously (e.g. from 71% in 1998 to 43% in the 2008 Census, nationwide), since new structures are predominantly made of fired bricks.

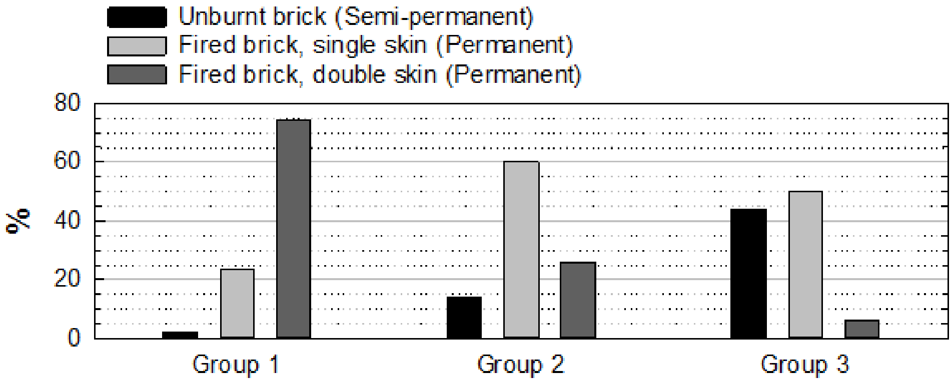


Figure 3: Results of the 2017 building survey summarised per area group.

The key observations from the survey results can be summarised as follows:

- In most areas, 50% to 60% of the permanent-type structures were built with single-skin walls, which are not recommended in the Safer Housing Construction Guidelines. With a small exception of low-rise structures built with larger size bricks of about 14-15cm wide, the majority of the single-skin walls were slender and vulnerable against lateral loads.
- Openings were poorly supported; less than 20% of the inspected buildings had proper lintels. The use of ring beams and wall plates to provide horizontal restraint to the masonry, in combination with the fixing of the roof truss, was rare. Judging from the conditions prevailing in the neighbouring structures, many of the ‘unknown’ lintel cases (Table 1) in the formal construction urban areas (e.g. Salima 712) are probably concrete or timber, but in all other areas, most of the unknown cases seem likely to have no lintels.

- More than 80% of the roofs were found to be of the gable type. An increased percentage of hipped roofs in some sub-urban and rural areas pertain to lightweight thatched roofs on small square-shaped semi-permanent houses, but the percentages of proper hipped roof trusses on new fired brick structures were very small. Against the recommendations of the guidelines, gable-type roofs are more popular in newer constructions, since current practice tends to use unstable and vulnerable gable walls to support a ridge beam to support the roof. Very few buildings had proper roof trusses. In terms of roofing material, the percentages of corrugated iron roofs with respect to traditional thatched roofs have increased significantly, which has been contributed by the Government's subsidy programme.
- 77% to 95% of the buildings in all areas were found to have a regular/rectangular shape with length-width aspect ratios normally between 2:1 and 1:1. These numbers do not include seemingly vulnerable extensions like heavy-weight porches and roof extensions (khonde) on isolated pillars, which were quite common in the surveyed areas.
- Semi-permanent houses were exclusively built using mud mortars, whereas double-skin permanent houses were built mainly using cement mortars. Single-skin permanent houses use both mortar materials with almost equal percentages; use of cement mortar is generally higher in urban areas than in rural areas.
- A strong correlation was observed between building materials and house dimensions. Houses made of unburnt bricks and mud mortars were consistently smaller, normally up to 7 m long with 1-3 rooms maximum. Single-skin houses made of fired bricks and cement mortar are normally up to 10 m long, whereas double-skin ones generally exceeded 10 m. The use of fired bricks and cement mortar often permit larger building layouts with higher walls and with more and larger openings.
- The overall rating of quality and damage/maintenance condition showed that more than 50% of the inspected buildings exhibited signs of structural damage caused by various mechanisms related to the masonry, the openings, the roof and the foundations, or signs of erosion/scouring, with insufficient protection, mitigation measures and maintenance.

3. Building Classification of Housing in Malawi

3.1 Building classification system

Building classification systems are commonly used to identify the basic typologies, according to their main structural characteristics, i.e. materials, load-bearing systems, connections between structural elements etc. To facilitate seismic vulnerability assessments, building classes can be directly related to the expected performance of buildings during an earthquake by assigning so-called 'seismic vulnerability classes'. Such a system has been developed as part of the Prompt Assessment of Global Earthquakes for Response (PAGER) project (Jaiswal and Wald, 2008), which operates on the basis of a global building inventory at a country-by-country level (Jaiswal et al., 2011). This inventory has been developed by combining numerous sources, including United Nations', UN-Habitat's (2010) and the (2002 version) World Housing Encyclopedia (WHE) databases and national housing census or expert reports. However, the PAGER database often lacks country-specific data, resulting in 'low-quality estimated' building stock data inferred from neighbouring countries.

Once building classes and their seismic vulnerability are defined, it is necessary to obtain reliable information of proportions of structures for individual building classes. Among existing building information, there exists significant discrepancy and uncertainty. In the previous 2002 version of World Housing Encyclopedia, Ngoma and Sassu indicated that 35% and 45% of houses could be classified as rammed earth and unburnt brick wall respectively, whereas 5% of the building stock was Wattle and Daub; the remaining 15% was unclassified, assumed to represent 'permanent structures' based on the 1998 Census data and their expert judgement. In contrast, the PAGER global database indicates that buildings in Malawi consisted of15% mud walls (M2), 19% unburnt/adobe blocks (A), 1% rubble stone masonry (RS), 14% unreinforced fired brick masonry (UFB), and 51% unreinforced concrete block masonry (UCB) (note: PAGER-based building classes are indicated in the brackets). These numbers were derived based on the building stock of the neighbouring country of Tanzania, assessed by the UN-Habitat 2007 global report and expert judgement.

The discrepancies between the above sources regarding the housing stock in Malawi are illustrated in Figure 4. The results from the 2017 building surveys are also included in the figure. The 2002 WHE dataset is comparable to the 2008 Census data, but there is clear evidence of changes in housing conditions over the years, indicating that housing conditions change rapidly in Malawi, traditional/semi-permanent houses being replaced with more permanent ones. On the other hand, there are considerable differences between the Census and PAGER inventory datasets, both in terms of material and typology. Although from Figure 4 it seems that PAGER and the 2017 building survey give similar data in terms of the traditional, semi- permanent, and permanent classifications, the results for seismic risk could be significantly different because there are significant variations of the seismic vulnerability between buildings that are categorised as 'permanent' according to the Malawi census. In this regard, more specific information about the buildings is needed, as demonstrated in the following section.

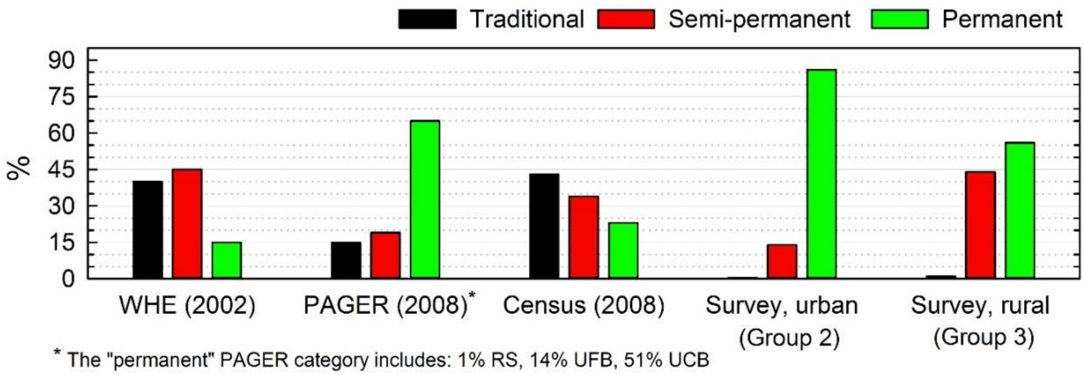


Figure 4: Comparison of housing stock information from the 2002 WHE database, Jaiswal & Wald (2008), the 2008 Malawi Census, and the 2017 survey results.

3.2 Comparisons of the global and local building stock data

The results from the 2017 building survey indicate that an updated estimation of the current local housing stock differs from those of the global building stock model. Malawian structures exhibit particular structural characteristics, which may lead to discrepancies in earthquake disaster impact estimates, compared to the global vulnerability models. To discuss the influence of the building classification differences in terms of seismic vulnerability, the main housing types in Malawi need to be classified. Using the PAGER system, the following three building typologies are relevant for housing construction in Malawi:

- **M**: mud walls, which can be further subdivided into **M1** and **M2**, without and with horizontal wood elements, respectively.

- **A**: adobe blocks, subdivided into **A1**: adobe block, mud mortar, wood roof and floors and **A2**: adobe block, mud mortar, straw and thatched roof.

- **UFB**: unreinforced fired brick masonry, subdivided into **UFB1** and **UFB4**, for mud and cement mortar, respectively.

  Based on the survey results presented in Section2, the percentages of buildings are estimated as follows:

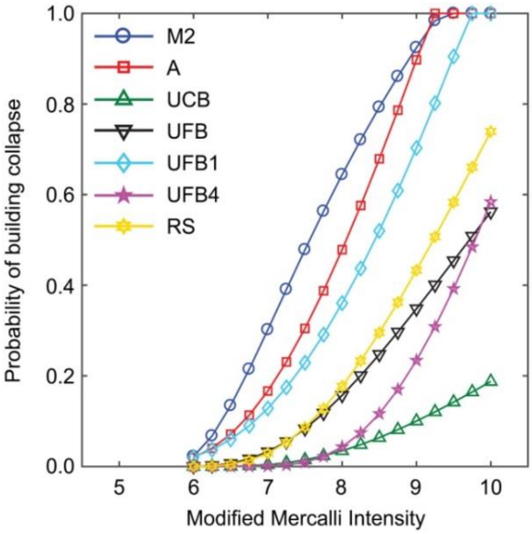
- In urban areas, given that the formal sector represents less than 10% of housing construction (UN-Habitat, 2010), it is considered that 10% of the housing stock is in the semi-permanent class (A1 and A2); 60% are fired brick – single-skin, of which around 50% have mud mortar (UFB1) and 50% have cement mortar

(UFB4); 30% are fired brick – double-skin with cement mortar (UFB4). In short, for urban areas, overall proportions of 0.1, 0.3, and 0.6 of buildings can be assigned to PAGER-based building classes A, UFB1, and UFB4 respectively. A further distinction might be possible for the double skin buildings having proper lintels or ring beams.

- For rural areas, the estimations mainly rely on the results for market towns, which are expected to lie somewhere between urban and pure-rural conditions. It can be assumed that: fired brick – double-skin buildings are rarely found in such areas; there is a clear majority of adobe structures, i.e. 60% adobe versus 30% fired brick having approximately a percentage of 50% each for mud mortar and cement; the proportion of traditional housing has been continuously dropping at a similar rate as between the previous two Censuses (i.e. 71% in 1998 versus 43% in 2008), thus it is inferred to be around 10% in 2018. In short, our best estimates of the building proportions in rural conditionsare 0.1, 0.6, 0.15, and 0.15 for the PAGER-based building classes M, A, UFB1, and UFB4, respectively.

These estimates, compared to the results of the field survey performed in 2002 in Machinga and Phalombe (Ngoma, 2005), indicate a 10% reduction of adobe block structures and a corresponding increase of fired brick structures in both urban and rural areas, which is consistent with a rapidly changing environment.

The importance of using realistic building data for seismic risk assessment in Malawi is evident, when comparing the predictions of the vulnerability models based on the global and local building data. PAGER adopts empirical seismic fragility curves for building collapse, as a function of modified Mercalli intensity (MMI), which is a common seismic intensity parameter (Jaiswal et al., 2011). Such seismic fragility curves are presented in Figure 5 for the building types that are relevant to Malawian structures. M2, A, and UFB1 are more vulnerable than the other building typologies. It is important to highlight the notable higher fragility of UFB1 (mud mortar) which is almost comparable to A, as opposed to class UFB4 (cement mortar). UCB exhibits significantly lower seismic vulnerability than the other classifications, but whereas PAGER assumed 51% of buildings in Malawi were of this type, the survey indicated these were very rare. Therefore, it can be expected that using the global building classifications underestimates the seismic risk for Malawi.



Building proportions of Malawian structures

Building class	PAGER	2017-survey, urban	2017-survey, rural
M2	0.15	0.0	0.1
A	0.19	0.1	0.6
UFB	0.14	0.0	0.0
UCB	0.51	0.0	0.0
UFB1	0.0	0.3	0.15
UFB4	0.0	0.6	0.15
RS	0.01	0.0	0.0

Figure 5: Comparison of the empirical seismic fragility functions for M2, A, RS, UFB, UCB, UFB1, and UFB4 by Jaiswal et al. (2011) in terms of MMI.

4. Conclusions

The results of the building survey presented in this paper have confirmed the transitional nature of informal housing in Malawi from traditional and semi-permanent types to more permanent ones. Due to limited resources, the poor quality of materials used and construction practice, the vulnerability of the housing stock remains high overall. There is still a considerable gap between the recommendations of the recent Safer Housing Construction Guidelines (Bureau TNM, 2016) and current practice, which needs to be filled with the implementation of appropriate policies and actions, to increase sustainability and disaster resilience of local communities. There is also a significant lack of building stock data that reflect actual housing conditions in Malawi. This is important because available seismic risk assessment tools, such as PAGER, rely on global building data, potentially misinforming policy decisions. Further efforts are warranted. The 2018 Census provides an opportunity to obtain a more comprehensive overview of the current situation of housing stock in Malawi. This study has also demonstrated that the conventional Census classification is not ideal, given that different typologies of housing stock need to be assigned to structural classes which can be further linked with seismic vulnerability classes in terms of seismic fragility functions.

The building survey was carried out as part of the PREPARE (Enhancing PREParedness for East African Countries through Seismic Resilience Engineering) project as a collaboration between the University of Malawi - The Polytechnic and the University of Bristol. In the subsequent stages of this project, more field surveys and experimental testing of typical Malawian masonry elements have been planned for 2018 and 2019. These data will be fed into numerical modelling of Malawian masonry houses to assess the seismic vulnerability of typical Malawian structures.

Acknowledgements

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Data Availability

This publication complies with EPSRC Open Access framework. All underlying data are provided within this paper.

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